PROGRAM

THURSDAY, AUGUST 15, 1957

9:00-9:30	REGISTRATION		DINKELSPIEL LOBBY
9:30-12:00	SESSION I (S) CHAIRMAN: F. E. TERMAN		DINKELSPIEL AUDITORIUM
	THE RESEARCH PROGRAM INTRODUCTION TRANSISTOR RESEARCH NETWORK THEORY HIGH-POWER TUBES AND MICROWAVE DEVICES		 F. E. TERMAN J. G. LINVILL W. W. HARMAN M. CHODOROW
10:45-11:00	RECESS		
	TRAVELING-WAVE TUBES AND GENERAL MICROWAVE AMPLIFIERS SYSTEMS TECHNIQUES RADIO STUDIES OF THE IONOSPHERE		D. A. WATKINS W. R. RAMBO O. G. VILLARD, JR.
	RESEARCH OF GENERAL INTEREST: STANFORD PARTICIPATION IN THE I.G.Y.		 O. G. VILLARD, JR.
12:00-1:15	LUNCHEON RECESS		
1:30-2:50	SESSION II A	RADIO STUDIES OF THE IONOSPHERE I	REHEARSAL HALL
	SESSION II B (C)	TRAVELING-WAVE AMPLIFIERS AND OSCILLATORS	AUDITORIUM
2:50-3:10	RECESS		
3:10-4:30	SESSION III A (S)	SYSTEMS TECHNIQUES I (CLASSIFIED RESEARCH)	REHEARSAL HALL
	SESSION III B	RADIO STUDIES OF THE IONOSPHERE II	AUDITORIUM
6:00	STEAK FRY AT ADOBE CREEK LODGE TRANSPORTATION AVAILABLE AT 5:30 AT WILBUR HALL AND AT DINKELSPIEL AUDITORIUM.		

FRIDAY, AUGUST 16, 1957

9:30-10:40	SESSION IV A	TRANSISTOR RESEARCH	REHEARSAL HALL
	SESSION IV B (C)	MICROWAVE DEVICES	AUDITORIUM
10:40-11:00	RECESS		
11:00-12:10	SESSION V A	NETWORK AND SYSTEM THEORY	REHEARSAL HALL
	SESSION V B	HIGH-POWER TRAVELING-WAVE TUBES AND KLYSTRONS	AUDITORIUM
12:10-1:15	LUNCHEON RECESS		
1:30-2:45	SESSION VI A (S)	SYSTEMS TECHNIQUES II EXPERIMENTAL ECM EQUIPMENT AND DEVICES	REHEARSALL HALL
	SESSION VI B	MICROWAVE ELECTRONICS	AUDITORIUM
2:45-3:15	RECESS		
3:15-	TOURS AND INDIVIDUAL CONFERENCES BY ARRANGEMENT		

FOR TOURS MEET AT STEPS IN FRONT OF DINKELSPIEL AUDITORIUM; FOR DETAILS OF TOURS, SEE P. 75

NOTE: ALL SESSIONS A MEET DOWNSTAIRS IN THE REHEARSAL HALL; ALL SESSIONS B IN THE MAIN AUDITORIUM.

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SESSION II A (1:30-2:50) (Rehearsal Hall)

RESEARCH STUDIES OF THE IONOSPHERE I (Unclassified)

CHAIRMAN: A. M. PETERSON

1. Radar Studies of 15th-Magnitude Meteors
(AF19(604)2193; P. B. Gallagher and V. R. Eshleman)

The particles responsible for the brightest and the faintest visual meteors (-10 to +5 visual magnitude) have masses in the ratio of 10^6 to 1. Still smaller particles can be studied by radio-echo techniques. Past radar studies of small meteors have been limited by system sensitivity to about the +10th magnitude; i.e., to trails created by particles having masses equal to or greater than 1/100 the mass of those particles which create the faintest meteors observable by eye.

A radar system permitting studies of meteors down to the 15th magnitude has now been constructed. It features a 23-Mc broad-side array of 96 four-element Yagi antennas arranged in the form of two parallel rows of antennas several wavelengths apart. Each row is approximately 2000 feet long. The array generates a fan-shaped radiation pattern that has a lobe structure in the meridian plane, and has a measured half-power beam width of 1.5 degrees. The theoretical gain of the antenna is 30 db. This antenna is fed from a 90-kw peak-power transmitter through a T-R arrangement, allowing the same antenna to be used for transmitting and receiving.

The following data have been obtained for the very small meteors with this equipment; the distribution of echo rates and amplitudes; diurnal echo-rate variation; day-to-day echo-rate variation; and particle velocities.

Over most of the measured amplitude range, the number of echoes of amplitude greater than A is inversely proportional to A. (This variation also applies to the larger meteors which have been studied in the past). However, for the very small measured echoes, there are sometimes fewer and sometimes more echoes than the number given by this simple law. During the early morning hours, when the total rate is at its daily peak, the number is greater, while for the rest of the day the number is less.

The ratio of the diurnal maximum to diurnal minimum rate of echo detection is as high as 100 to 1, as compared to less than 10 to 1 for larger meteors detected with less directive antennas. The maximum rate (greater than 6000 echoes per hour) occurs in the morning, as would be expected for this north-directed antenna beam. However, the duration of the morning peak of activity is unusually short, being less than two hours. Day-to-day echo rates for the same time of day vary by more than two to one. There is a preliminary indication of an approximately monthly variation of the maximum echo rate.

Velocities of the very small meteors have been measured from the Fresnel diffraction fluctuation of the echo. However, these patterns are unusually irregular, making accurate velocity determina-

tions very difficult.

Measurements of the characteristics of very small meteors should provide new knowledge of (1) the number-mass distribution of interplanetary dust, (2) the distribution in space of this material, (3) the total amount of ionization created by meteors, and its role in ionospheric-scatter and meteor-burst propagation, (4) the physical nature of meteoric particles, and (5) the possible correlation of the rate of influx of meteoric material with world-wide rainfall statistics.

It is now apparent that the meteor size spectrum extends to smaller particles than can be detected with the present equipment. It is hoped that a more powerful transmitter can be obtained in order to extend the radar studies to these smaller particles.

2. *The Initial Radius of Meteoric Ionization Trails*
(Task 24D; L. A. Manning)

When a meteor passes through the lower E-region, it produces to the first order a line distribution of ionization in its path. It has been usual to compute the strength of meteoric echoes by assuming diffusion, with a fixed coefficient of diffusion, from this initial line distribution, although sometimes it has been thought that the ionization is distributed initially with a radius of one electronic mean-free-path length. However, more careful study shows that when the trail is first formed, the neutral and ionized atoms of meteoric material are moving with about 100 times thermal velocity. Diffusion of the trail is thus very rapid at first. Kinetic-theory calculations indicate that this rapid initial diffusion causes the trail to expand to a radius of about 14 times the mean-free-path length before the diffusing particles reach equilibrium temperature. Because neutral and ionized atoms differ in collision cross-sections and hence in free-path length, it can be said that there will be two meteor trails created--the neutral 'atom trail' and the 'ion trail.' The atom trail is about five times the size of the ion trail.

Calculation of the returned signal from an ionization trail, taking into account the finite particle velocity, shows that the transient expansion is so rapid that the signal may correctly be computed on the assumption that the ionization is formed instantaneously at an initial radius of 14 ionic mean-free-paths. At the higher meteor heights and radio frequencies, initial radius is the limiting factor in meteor detectability. It is predicted from the above theory that a rather sharp reduction in observed echo rate should occur at a frequency of roughly 100 megacycles; this drop-off is in fact observed in practice. The attenuation which produces this change in rate increases with increasing frequency up to about 50 db for under-dense trails at UHF. This signal-strength reduction is multiplicative with that occurring when the normal diffusion-decay time-constant is small compared with the time required for the meteoric particle to cross the first Fresnel zone. At the usual observing frequencies, the maximum height of detection is sharply limited by the

rapid increase of initial radius with height. Detectability of the less-densely ionized over-dense trails is affected at the same heights and frequencies as for under-dense trails.

3. Oblique Meteoric Echoes From Over-dense Trails
(Task 24D; L. A. Manning)

It is now well known that for under-dense meteoric ionization trails, i.e., those with line densities less than about 10^{14} electrons per meter, the echo duration at a given frequency is proportional to the square of the secant of the forward-scatter angle. The resulting large increases in the duration with obliquity of the path for under-dense-trail echoes are of great importance in the practical application of meteoric echoes in communication circuits. Experimental studies of echo durations from over-dense trails (line densities greater than 10^{14} electrons per meter) on oblique paths have shown, however, that the same increase in duration with obliquity is not observed. In the present study, the ray paths in an over-dense Gaussian trail have been computed by the method of geometrical optics. Both the dependence of duration on obliquity, and the polar scattering diagram versus echo duration have been computed. (For simplicity, it is assumed the incident ray is perpendicular to the meteoric path or radiant). It is found that no simple power secant law of duration applies. No increase in duration relative to the duration at back-scatter occurs over an oblique path unless the transmitted ray is deviated from the forward direction by less than ninety degrees. For smaller deviations, the duration does increase, but if the results are force-fitted to a secant law, the required exponent is generally less than one-half. It is found also that for durations greater than those possible at back-scatter, a peak in the polar scattering diagram occurs in the most nearly backward direction. There is also a peak in the original wave direction.

4. Some Characteristics of Radio Communication Via Meteor Ionization Trails
(AF19(604)2193; V. R. Eshleman and R. F. Mlodnosky)

The intermittent vhf signal propagated over long ranges (up to 2000 km) by reflections from meteor ionization trails makes possible an important new technique for radio communication. In this 'meteor-burst' communication technique, the required transmitter power and antenna size are considerably less than for communication via the continuous vhf scatter signal supported by smaller meteors and other scattering sources in the lower ionosphere. The wavelength dependence of the information capacity of meteor-burst propagation is approximately $\lambda^{2.7}$, which may be compared with approximately $\lambda^{4.7}$ for continuous communication. It may be said that the terminal equipment is better matched to the propagation medium when provision is made to send and receive information intermittently. As a result it should be feasible to use considerably shorter wavelengths for meteor-burst communication than can

be used for continuous ionospheric-scatter communication, thereby increasing the number of channels available for long-range communication and reducing the self and mutual interference now encountered in the lower vhf band.

The directivity of radio reflections from meteor trails, and the distribution of trail orientations (radiants), control the directional properties of meteor propagation. The gross features of these directional properties for an east-west path in northern temperate latitudes are such that, for maximum number of meteor reflections, the antennas at the transmitter and receiver should be pointed north of the great-circle bearing for the hours centered on 0600, and south of this bearing for the hours centered on 1800. The optimum off-path angle may be as great as 20°. For a north-south path, the beams should be pointed west of the path at night, and east of the path during the day. These gross features appear to repeat each day. In addition, short-term fluctuations in the radiant distribution have been noted, these fluctuations being due to heretofore undetected meteor showers of very short duration. It appears that the information capacity of meteor-burst and ionospheric-scatter systems could be markedly increased by varying the bearings of the antenna beams according to the known diurnal variations in meteor radiants. In addition, it may be possible to put to use the short-term fluctuations in the radiant distribution by means of a radar which can continuously monitor the changing radiant distribution, and 'instantaneously predict' the optimum antenna bearings for the communication circuit.

It appears important to extend the studies of meteor radiants to smaller meteors. This could be done with a more powerful transmitter and a larger rotating antenna than was used in obtaining the above results.

SESSION II B (1:30-2:50) (Auditorium)

TRAVELING-WAVE AMPLIFIERS AND OSCILLATORS (UNCLASSIFIED)

CHAIRMAN: G. WADE

1. A Study of the Wideband Kilowatt Amplifier Problem at S-band and Higher Frequencies.

(Project 490B-84(U); D. A. Dunn, R. P. Lagerstrom, W. R. Luebke, P. A. Brennan)

A satisfactory traveling-wave amplifier with bandwidth greater than 50% and pulsed power output greater than one kilowatt can be built at frequencies below about 4000 Mc using conventional design techniques. At these frequencies and with these bandwidth and power capabilities, tubes with at least a 10% duty cycle, and probably c-w tubes as well, are possible. For frequencies at and above X-band, a new approach is required if the tube, including focusing structure, is to have a reasonable size and weight and if a reasonably high average-power capability is to be provided.

Several aspects of this problem are under study, including new slow-wave circuits for 50% or greater bandwidth, and depressed-collector operation of traveling-wave tubes.

The conventional single-helix circuit, which could provide the desired bandwidth if scaled down to X-band size, would be limited in power output because of reduced heat dissipation and reduced beam cross section and would require a very high magnetic field and a heavy solenoid. The use of oversized helices, on the other hand, is restricted by the threat of backward-wave oscillations near wavelengths of twice the helix circumference. An 'ultimate' circuit would have a much larger diameter than present circuits, no backward-wave interaction difficulties, and would be all-metal. No circuit is presently known with these attributes and with a 50% bandwidth. However, from the present studies it appears that new circuits may be developed which are substantially better than the single helix in these respects. A number of alternatives will be discussed including some bifilar helices with straps and other discontinuities introduced in order to provide support, cooling, and suppression of backward-wave oscillations.

The possibility of improving efficiency by means of a multi-segment depressed-voltage collector permits a considerable increase in the freedom of design in this type of tube. Such a collector would collect the entire beam at a very low voltage when there is no r-f input and would split the beam between two or more segments at different voltages when r-f input is supplied. In a low-duty-cycle application, the tube could be operated with a c-w beam and be ready to amplify at all times, and yet the power-supply drain would be low. Some preliminary calculations have been made for a proposed two-segment collector involving both longitudinal and transverse electric fields together with the usual longitudinal magnetic focusing field. The results of these calculations indicate that

the beam efficiency can be appreciably increased using electrode geometries that would not substantially increase the mechanical complexity of the tube.

Experimental work on an X-band one-kilowatt amplifier incorporating some of these ideas is in progress and will be discussed.

2. Hollow-Beam Focusing Using Radial Electric and Periodic Electric or Magnetic Fields

(Project 406W-84(U) and 313T-78 (U); C. C. Johnson, Y. Hiramatsu)

In most conventional systems employing microwave tubes, a solenoid and associated power supply are required. Any focusing system which can eliminate the solenoid leads to weight reduction, compactness, and efficiency improvement.

Two systems are described which achieve this end result. One system is purely electrostatic and uses radial and periodic fields to obtain focusing. The radial field is established by an inner rod at a voltage slightly below the beam voltage. The periodic fields are established by a series of rings surrounding the beam at voltages alternately above and below the beam voltage. The periodic fields exert an inward force, and the radial field, an outward force. These forces are used to cancel space-charge forces at the beam boundaries to obtain focusing. Possible r-f structures which could be incorporated into this focusing scheme are numerous. For example, a bifilar helix would be employed to establish the periodic fields as well as to act as the r-f structure. A monofilar helix or any other structure of circular cross section could replace the inner rod.

The second system is much like the first, except that the periodic fields are magnetic instead of electrostatic. Radial fields are set up by an inner rod and an outer cylinder surrounding the beam. The periodic magnetic fields are established by a series of magnets external to the outer cylinder which are alternately of north and south polarity. These fields are then used to cancel the space-charge forces at the inner and outer beam boundaries. The r-f structure can take the place of either the inner rod or the outer cylinder. While this focusing scheme requires periodic magnets which are not required in the previous system, it relaxes the requirement for compatability between the focusing structure and the r-f structure.

These systems can focus hollow beams which are useful for low and medium power tubes.

The system employing purely electrostatic fields has been investigated experimentally. A well-focused beam of micro-perveance 4 was obtained with 97 per cent transmission at a beam power of 15 watts. Beam trajectories have been obtained from the IBM 650 Computer which show the effects of 'over-focusing' and of imperfect entrance conditions. Preliminary results indicate that a beam can be focused despite considerable variation from optimum entrance conditions. This is in contrast to many focusing systems which are very critical in this respect.

3. Backward-Wave Oscillator Studies (Project 403W-24(U); J. Gewartowski)

The backward-wave oscillator has proven to be a versatile and useful device for laboratory signal generators, communications systems, and countermeasures equipment. Because of the highly nonlinear nature of the electron interaction process in the oscillator, a complete theoretical analysis is very complicated and to this date has not been performed.

This work is an experimental study of the dynamic electron interaction mechanism in the backward-wave oscillator. The instantaneous current and velocity of a representative portion of the electron beam reaching the collector are obtained experimentally by means of a beam analyzer. The values of current and velocity thus obtained depend upon the level of oscillation, which is determined by the ratio of the actual total beam current to its value at the start of oscillation. Data have been obtained for a series of levels of oscillation.

In order to observe the instantaneous current and velocity with as much accuracy as possible, the data were taken on a specially built tube scaled up in size and down in frequency. The result is an 80-Mc tube, twelve feet in length, which can be voltage tuned from 40 Mc to over 120 Mc.

The tube uses a sheet beam and an interdigital line. A small hole in the collector allows a few microamperes of the beam to pass into the beam analyzer. The beam analyzer consists of focusing lenses, a crossed d-c electric and d-c magnetic field for velocity separation, r-f deflection plates, and finally a fluorescent screen. The r-f deflection plates cause the unmodulated beam to describe an elliptical path on the fluorescent screen. The crossed d-c electric and magnetic fields are balanced so that the unmodulated beam is not deflected by them. When the tube is oscillating, both current and velocity modulation exist on the beam, which alter the appearance of the fluorescent-screen trace considerably. Since the r-f deflection plates are synchronized to the output of the tube, a stationary pattern appears on the screen. The velocity separator is arranged so that velocities different from the d-c beam velocity are indicated by vertical deflections from the reference ellipse. Instantaneous current is measured from the brightness of a small portion of the trace. Position around the ellipse gives a time base for these measurements.

These patterns are photographed and analyzed using an optical densitometer-comparator. By this means the nonlinear operating characteristics of the backward-wave oscillator can be determined in detail. Data on instantaneous current and velocity as a function of r-f phase contribute significantly to an understanding of the mechanism by which the oscillation level is reached.

4. The Helitron Oscillator (Project 404W-24(U); D. A. Watkins and G. Wada)

The HELITRON oscillator is a new type of voltage-tuned oscillator which can be built to operate at

moderate power levels in the 500-Mc to 10-kMc range. It requires no magnetic field and has a tuning characteristic superior to that of the type-'O' backward-wave oscillator.

The device is called HELITRON because the electron beam of rectangular cross section traverses a helical path between an outer cylindrical 'sole' electrode and an inner cylindrical r-f circuit. The r-f circuit is maintained positive with respect to the sole, thus providing an inward radial electric force which, when balanced against the outward centrifugal force, results in stable focusing for the beam.

The angle of the helical path is determined by the mounting angle of an electron gun which launches the beam at the beginning of the interaction region.

The r-f structure consists of a four-segment cylinder which propagates a TEM wave for which the four segments are alternately plus-minus-plus-minus. Thus the r-f interaction is between the electrons and the r-f field in the four gaps. When a TEM wave is visualized to travel from the collector end to the gun end of the structure, backward-wave interaction will occur at a frequency such that the electrons travel from one gap to the next in a little less than one-half cycle. Results of testing an experimental model are as follows:

The tube tunes continuously from 1.2 to 2.4 kMc with a power output ranging from 2 to 10 milliwatts. To cover this frequency range, the sole-to-circuit voltage is varied from 700 to 1700 volts. Thus a 2.5-to-1 voltage change covers a 2-to-1 frequency range. Second-harmonic output is more than 25 db below the fundamental over the range.

The HELITRON oscillator appears to have the following advantages over type-'O' backward-wave oscillators or voltage-tuned magnetrons: (1) No magnet is required. (2) The efficiency is potentially higher than that of the type-'O' backward-wave oscillator. (3) Tuning voltage and frequency are nearly proportional. (4) The device is relatively easy to fabricate.

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SESSION III B (3:10-4:30) (Auditorium)

RADIO STUDIES OF THE IONOSPHERE II (UNCLASSIFIED)

CHAIRMAN: O. G. VILLARD, JR.

1. *The Magneto-Ionic Duct--A New Means for Long-Distance Radio Transmission at Very Low Frequencies*

(Nonr-225(27), also AF18(603)126 and Y/6.10/20; R. A. Helliwell and E. Gehrels)

Echoes of radio signals from station NSS on 15.5 kc in Annapolis, Maryland (geomagnetic latitude 50° N), with delays up to nearly one second have been detected by a Stanford University observer at Cape Horn, South America (45°S). The signal was a special pulse of one-quarter-second duration, repeated every two seconds. Most of the observations were made for 15-minute periods at night during January and February, 1957.

These observations provide the first controlled test of the Eckersley-Storey theory of whistler propagation. Whistlers are audio-range electromagnetic signals, usually of descending frequency, and were shown by Eckersley to result from the dispersion of lightning energy. Storey advanced the hypothesis, supported by considerable data, that the path of propagation extends between the hemispheres through the outer ionosphere, following lines of force of the earth's magnetic field. Such paths, which we have termed 'magneto-ionic ducts,' may extend as far as 20,000 miles above the surface of the earth. The group velocity along these ducts is of the order of ten per cent of that in free space.

Discovery of the NSS echoes opens up new possibilities for long-distance communication at very low frequencies and has a significant bearing on low-frequency navigation systems. It also provides a powerful new tool for determining the distribution of ionization in the outer ionosphere, a little understood but extremely important link between the sun and the earth.

The main results and conclusions are summarized as follows:

1. NSS echoes with group delays of from 0.3 to 0.9 second have been observed at 15.5 kc at night. The close similarity of these delays to those observed in conventional whistler propagation provides new evidence in support of the Eckersley-Storey theory of whistlers.

2. NSS echoes were frequently heard when whistlers were entirely absent. This absence was probably due to a lack of suitable lightning sources at the proper location, and not to poor propagation conditions in the magneto-ionic duct as had previously been thought.

3. Split echoes and regular deep fading were often observed; this suggests the presence of multiple paths of propagation of variable relative phase.

4. The observed echo intensities were 10 to 30 db below that of the direct wave whose nighttime intensity was 150 microvolts per meter. According to present theory, the receiver was near the edge of the 'effective' area surrounding the

opposite end (called the 'conjugate' point) of the field-line path originating at the transmitter. This relationship suggests that echo strengths comparable to or greater than the direct wave may be found near the conjugate point. Under these conditions, the new mode would be an important factor in vlf communication.

5. The long and variable delays of the observed echoes can be expected to interfere seriously with the operation of phase-sensitive vlf navigation systems.

6. The new technique has important advantages over whistlers for the study of the outer ionosphere. Unlike the lightning source, the vlf transmitter can be turned on at will and its location and radiation properties are readily determined. It should now be possible to obtain valuable new data on the distribution of ionization far beyond the known layers of the ionosphere. Such knowledge correlated with solar and other geophysical data can be expected to lead to a better understanding of the mechanisms of magnetic storms and aurorae.

Detailed plans are being formulated for setting up further NSS listening stations in the Cape Horn area, and, for the first time, in Antarctica. Every effort is being made to complete the installations by this coming fall. There are two reasons for haste: (1) whistler recordings being made for the IGY, which started July 1, 1957, are needed to aid in data interpretation, and (2) desirable field sites and personnel in the southern hemisphere are available only during the IGY.

2. A Microwave Spectroheliograph for Studying the Solar Control of the Ionosphere

(AF18(603)53; R. N. Bracewell)

The Stanford microwave spectroheliograph, which is nearing completion, will scan the sun in television fashion with a very narrow pencil beam, to build up a 'photograph' of the sun taken with radiation which is emitted in the S-band portion of the radio-frequency spectrum.

Such a spectroheliogram, to borrow the optical term for a monochromatic picture of the sun, will reveal aspects of the sun quite different from those to which we are accustomed from optical observations. The principal features of a microwave spectroheliogram will be: (1) the lack of circular symmetry in the quiet-sun radiation, (2) the presence of concentrated areas whose brightness is much greater than that of the surrounding quiet areas, and (3) the occasional outburst of radiation associated with chromospheric flares. It is also expected that the radio sun will be ten per cent larger than the visible sun. These expectations are based on a small number of laborious pioneering observations which have already been carried out elsewhere. What further phenomena will emerge when regular observations are instituted cannot, of course, yet be guessed.

The basic purpose of the program is to provide new knowledge about the sun and its influence on the earth's ionosphere. What information is already available about the sun is being utilized to the full

at present, and very large investigations are being undertaken to find the best use to which existing solar data can be put to improve forecasts of ionospheric propagation and to lessen the effects of solar disturbance. However, the available data are principally optical, and the optical effects do not necessarily originate at solar levels at which the strongest solar disturbances manifest themselves. For example, the deep-lying and very thin stratum of the sum from which white light comes exhibits hardly any day-to-day variation in emission, whereas the layers of the chromosphere from which microwaves come are quite variable in output. These chromospheric levels are believed to be the source of the ionizing ultraviolet radiation which causes variability of the earth's ionosphere.

Thus observations with the new instrument can be expected to contribute data on an important part of the sun which hitherto, as a result of its virtual transparency, has been accessible only with difficulty to optical study. It is also expected that the liaison with radio scientists, resulting from the conduct of this work within a group experienced in ionospheric radio propagation, will lead more readily to practical application then is usual with astronomical research.

3. Long-Distance Transmission Supported by Multiple Reflections From the F-Layer of the Ionosphere Without Intermediate Ground Reflections (Task 24D; AF19(604)1830; O. G. Villard, Jr. and A. M. Peterson)

By means of the ground-backscatter sounding technique, it is possible to demonstrate the existence and relative importance of ionospheric modes of transmission involving two or more successive reflections from the F-region without an intermediate reflection from the ground. In order that such transmission be launched, the ionosphere must depart from spherical symmetry in a suitable manner; in order that the energy eventually be returned to the earth, a second departure from symmetry is required. Such departures from symmetry are frequently provided in the morning and evening hours by the normal daily buildup and decay of F-layer ion density, which results in the appearance of effective ionospheric tilts. It is found that these tilts exert a powerful effect on radiation taking off from a given transmitting antenna at the lower vertical angles.

Strong tilts are encountered almost daily in equatorial regions, owing to the way in which the F-layer behaves in the vicinity of the magnetic equator. These tilts result in the regular appearance of two and three successive F-layer reflections, without intermediate ground reflection. Often this propagation takes place at frequencies considerably higher than the highest which will support conventional multihop transmission; it may in fact provide an explanation for the so-called 'anomalous' transequatorial propagation. At temperate latitudes, tilt-supported transmission can, at a given radio frequency, be shown to be present in one direction or another for a fraction of the time which can be as

high as 20 per cent. Such transmission has been consistently observed to the north of Stanford owing to the normal daily gradient of ionization in that direction.

Tilt-supported propagation modes have a number of interesting properties. They display surprising strength, owing both to the existence of a novel type of ionospheric focusing, and to their relatively low attenuation, since energy losses in the D-region and at the ground are avoided. In addition, the effective skip distance for this type of transmission is much less dependent on the operating radio frequency than is the case with conventional symmetrical reflection. Finally, if the layer tilt or distortion from spherical symmetry is severe enough, the tilt mode may be effective at frequencies appreciably above the conventional MUF.

The significance and prevalance of tilt-supported transmission has not previously been appreciated because pulse, rather than c-w techniques are needed to separate the various types of propagation from one another. Since these modes are normally effective over transmission paths of given length at given times of day and at given seasons of the year, it is not surprising that they should have escaped notice until systematic observations with rotating antenna backscatter sounders had been carried out.

It seems likely that methods for predicting and utilizing tilt-supported propagation can be found, and that application of such methods will result in a notable improvement in the efficiency with which the ionosphere can be utilized.

SESSION IV A (9:30-10:40) (Rehearsal Hall)

TRANSISTOR RESEARCH (UNCLASSIFIED)

CHAIRMAN: J. G. LINVILL

1. *Transistor Theory and Circuits (Task 24C; J. M. Pettit)*

a. Transistor Theory: High-Frequency Equivalent Circuits.

A study has just been completed on large sample groups of two major types of junction transistors: 2N123 alloy pnp and SB100 surface-barrier types. The results include: (1) proven measurement techniques for obtaining device parameters (r_b', C_c, f_α, etc.,) and high-frequency admittances (y_{11}, y_{12}, etc.,) up to 30 Mc; (2) evaluation of our high-frequency equivalent circuit, previously developed by Middlebrook and Scarlett. The equivalent circuit can now be used with confidence to predict high-frequency admittances of a transistor up to and beyond half the alpha-cutoff frequency.

b. Transistor Circuits: Amplifier Stability

A year ago we reported a design technique for assuring a specified stability margin in a one-stage transistor amplifier--in a frequency range where the internal feedback in the transistor produces potential instability--by adjustment of source and load conductances rather than by neutralization. This work has been extended to the more complex case of a multi-stage amplifier, employing a two-terminal network plus an ideal transformer for the interstage coupling. Representative two- and three-stage amplifiers have been designed and constructed for experimental verification.

2. *Transistor Video Amplifiers (Project 292C-84(U), R. M. Scarlett)*

This project is concerned with the design of high-gain pulse amplifiers with short recovery time following an overloading pulse. A configuration employing alternate common-collector and common-emitter stages has been found useful for obtaining good gain and rise-time performance, and also lends itself well to direct coupling which aids in obtaining good recovery time. Overall d-c feedback is used to stabilize the operating point against temperature changes, and results in very simple circuitry. A six-stage amplifier using SB100 surface-barrier transistors gave a gain of 90 db with 0.18-μsec rise time, the recovery time after a 5-volt, 1-μsec pulse being less than 10 μsec. The performance is substantially constant to 60°C. For higher-temperature applications, a silicon-tetrode amplifier employing common-emitter stages with shunt feedback has been designed. Four 3N26 stages gave a gain of 80 db with 0.2-μsec rise time.

3. *Applied Transistor Research (Project 755K-51(U), M. McWhorter)*

a. Video Amplifiers Using Emitter Degeneration.

A design method for obtaining specified gain and bandwidth in multi-stage amplifiers has been completed. Common-emitter stages with a parallel R-C compensating circuit in the emitter lead are used. The design emphasizes maintenance of a good transient response (overshoot of 3% or less). The finished design is accomplished with a minimum of computation with the aid of two charts which have been prepared. (A paper on this subject will be given at WESCON.) A number of amplifiers using this approach have been built. One uses four RCA 2N24M's to give 4.2 Mc bandwidth, 65 db gain and 5% overshoot. These values compare well with the design values of 4.1 Mc, 67 db, and 4% respectively.

b. A Transistorized Sweep Generator.

This generator provides a sweep voltage suitable for deflecting an oscilloscope. Therefore, it is easily synchronized to high-frequency signals of almost any waveform, and it delivers a very linear sweep. The circuit used is basically a multivibrator driving a bootstrap sweep generator. Several novel ideas are used to de-couple the synchronizing signal from the multivibrator and the MV from the bootstrap circuit to prevent false sweeps. Also the sweep speed is made to be independent of the MV operation. Most bootstrap circuits have relatively long recovery times if very linear operation is desired; however, this circuit recovers very quickly because pnp and npn transistors are used in combination to recharge the sweep capacitor. Hence the recovery time is only a few per cent of the sweep time. Sweep times of 5 sec to 20 μsec have been achieved with amplitudes of 65% of the supply voltage and linearity of about 1%. Studies are now being made of pick-off circuits of precision suitable for precision checking of the sweep linearity.

This sweep has been used in combination with the high-output-voltage transistor amplifier described last year to give sweeps of 200 volts peak-to-peak. This is adequate to deflect small cathode-ray tubes.

c. Logarithmic Attenuators

Logarithmic attenuators for pulse use are currently being investigated. These make use of the exponential relation between current and voltage in some silicon diodes. Initial experiments show considerable promise: one attenuator operates with 0.1-microsecond pulses, has a dynamic range of 50 db and an output voltage within 5% of being truly proportional to the logarithm of the input current.

4. A Transistorized Pulse-Sorting System
(Project 755K-51(U), G.S.Bahrs)

Through a joint effort by members of Group Q (Applied Electronics Laboratory) and the transistor group, circuits have been developed that provide a pulse 'window' which responds only to pulses whose width and amplitude simultaneously fall within adjustable, pre-set limits.

The system is organized around a three-input AND circuit which is connected to (1) a pulse amplitude discriminator, (2) a pulse width

discriminator, and (3) a one-shot multivibrator that is triggered by the trailing edge of the incoming pulse. The amplitude and width discriminators each incorporate memory. The amplitude discriminator develops and retains an output if the input signal amplitude exceeds a pre-set threshold level. The width discriminator develops and retains an output if the pulse width exceeds W but is less than $W(1+\Delta)$; where W and Δ are both adjustable. The pulse from the one-shot multivibrator, occurring at the completion of the incoming pulse, serves to interrogate the amplitude and width discriminators; i.e., operation of the interrogation one-shot multivibrator leads to an output from the AND circuit if, and only if, outputs are present from both the amplitude and width discriminators.

SESSION IV B (9:30-10:40) (Auditorium)

MICROWAVE DEVICES (UNCLASSIFIED)

CHAIRMAN: D. A. DUNN

1. *Microwave Frequency Division (Project 189B-78(U); R. W. Grow and D. A. Dunn)*

The process of regenerative frequency division was first described many years ago by R. L. Miller, (R. L. Miller, *'Fractional Frequency Generators Utilizing Regenerative Modulation,'* Proc. IRE, vol. 27, pp. 446-456; July, 1939.) Basically the operation of a regenerative frequency divider depends on the use of a mixer and a feedback loop to feed the amplified output of the mixer back to one of the inputs of the mixer. Under these conditions, if the loop gain is sufficiently large, the amplitude of the output of the mixer varies as the amplitude of the signal applied to the other input. It is apparent that in this case the output frequency must be just one half of the input frequency. If a frequency multiplier were also inserted in the feedback loop, then a frequency f/n, with n greater than two, could be produced in the device.

A year ago the operation of a microwave divider which produced an output frequency which was 3/2 of the input frequency was described. Since that time a forward-wave device and a backward-wave device have both been successfully operated to produce division by two. In each of these devices an input signal is applied to the first helix to modulate the electron beam and the output is taken from the second helix. An external feedback loop is necessary with the forward-wave device but not with the backward-wave device. The amplitude of the output of the backward-wave type of divider was found to be quite unstable. Our understanding of these devices has increased considerably in the past year and the instability of this type of divider has now been explained.

Since the nonlinear element of the mixer is the electron beam, it is necessary to understand the nature of the mixing process of the beam. Recent theoretical work on mixing here at Stanford Electronics Laboratories by DeGrasse has led to some important conclusions which have been utilized in the latest frequency-divider tube. For instance, if a beam is modulated by two frequencies with the same angular field variations, then the difference frequency in the beam will have no angular field variation. Hence a forward-wave helix would be necessary to couple the difference frequency from a beam modulated by two backward-wave helices, each having one angular variation around the beam circumference. This fact undoubtedly accounts for the amplitude instability noted for the two-helix backward-wave type of frequency divider. To investigate more fully these modulation effects, a five-helix frequency-divider tube has recently been built and tested. The latter tube was built to permit several different experiments to be performed, each using different sets of helices. Several modes of operation contain a frequency multi-

plier in the feedback loop to permit division by a number greater than two. An important result has been the increased amplitude stability of this device. The work on this project is presently directed to the investigation of the conditions necessary to start the device at frequencies resulting from division by numbers greater than two.

2. Traveling-Wave-Tube Frequency Mixers.

(Project 386T-47(U); R. W. DeGrasse and G. Wade)

One purpose of this work has been to investigate the possibility of using TWT mixers to replace the conventional crystal-diode mixer employed in microwave superheterodyne receivers. The results of a number of experiments on traveling-wave-tube mixers show that efficient frequency conversion can be obtained from microwave signal inputs to microwave intermediate frequencies as well as to intermediate frequencies as low as 30 Mc. Conversion gains as high as 30 db and full traveling-wave-tube saturation power output at the intermediate frequency are obtainable. TWT mixers may also be used as regenerative frequency dividers.

The frequency conversion effects to be discussed are obtained from the large-signal saturation effects in an electron beam. Consequently, conventional TWT construction techniques can be used in the construction of TWT mixers.

Such TWT mixers may posses a number of important advantages over crystal mixers. The TWT mixer has relative freedom from burnout from high-level input signals. It is capable of considerable conversion gain with i-f bandwidths as wide as 1 kMc. Local-oscillator isolation can be substantially improved by the use of separate local-oscillator and signal couplings to the mixer tube. Finally, high-level microwave mixing is possible since full saturation power is available at the i-f output.

Previously, conventional TWT's have been operated as mixers with 30-Mc i-f outputs. These tubes have given overall conversion gains 30 to 40 db less than the small-signal gains of the tubes as amplifiers. We have found that the use of a downward voltage-jump and a low-voltage drift tube following a TWT amplifier section greatly increases the conversion gain. Such an experimental mixer having an S-band input gave a +7 db conversion gain from r-f input to 30-Mc i-f output. This tube had a small-signal gain of +11 db, just 4 db more than the conversion gain. An i-f output power of +10 dbm was obtainable. It is presently believed that such a TWT mixer will have a noise figure approximately the same as its noise figure when operated as an amplifier.

A traveling-wave-tube mixer with very wideband microwave i-f output may be designed using an input helix section for input signal amplification and a second helix section for i-f signal amplification. Two such double-helix mixers have been tested.

The first mixer tube operated with an S-band input and gave 30 db conversion gain to an i-f of 1200 Mc with a 20-Mc bandwidth. With a 200-Mc bandwidth, a conversion gain of 16 db could be obtained. The

maximum i-f output power was +15 dbm.

The second double-helix mixer had an input frequency range of 7.5 to 10 kMc. The i-f output was centered at 2.5 kMc with a 1-kMc bandwidth. The tube gave a conversion gain of +21 db.

The above tube did not have a low-noise electron gun and as a result its noise figure was about +22 db. It is interesting to compare this tube with a crystal mixer designed for the same i-f bandwidth. Assuming a -12-db crystal-mixer conversion gain, we see that, to obtain the noise figure and conversion gain of the TWT mixer, a TWT i-f amplifier following the crystal mixer would be required to have a noise figure of about 10 db and a gain of 33 db.

A theoretical study of the mixing phenomenon in an over-modulated electron beam has resulted in the development of a design theory for TWT mixers. This theory has been successful in predicting the conversion gain of TWT mixers. The theory is not a great deal more complicated than linear TWT theory and makes possible rapid design calculations.

3. Noise, Gain, and Bandwidth Considerations of the Variable-Parameter Amplifier

(Projects 210N-24(U) and 303T-84(U); H. Heffner, K. Kotzebue, G. Wade)

A theoretical investigation has been made to determine the noise, gain, and bandwidth characteristics of the general variable-parameter circuit (similar to the circuit analog for the ferrite amplifier proposed by H. Suhl, PHYSICAL REVIEW, April 15, 1957). The basic circuit and its operation are illustrated in the following description. A variable capacitor is connected in series with two parallel-resonant tank circuits, the three elements forming a closed loop. If the value of the capacitor is caused to vary sinusoidally about some average value at a frequency equal to the sum of the two resonant frequencies of the tank circuits, under the proper conditions oscillations can be set up in the tank circuits at their respective frequencies. Power is thus 'pumped' from the varying capacitor into the two tank circuits. Assume that an output load is coupled to one of the tanks and that the capacitor variation is reduced to a value just below the point where oscillations occur. Stable amplification then results for a signal coupled into the loaded tank at the tank's resonant frequency.

Several physical embodiments of this principle of amplification have been proposed. As previously mentioned, Suhl suggested a microwave structure containing a ferrite sample, the pumping power to be coupled to the lower-frequency signal through nonlinearities in the motion of the magnetization in the ferrite. At Stanford, we are investigating the feasibility of using electron beams or ferroelectric materials to provide the necessary variable reactance.

Regardless of the embodiment, the theory reveals certain inherent characteristics of the device. For high gain, the 'idling' tank circuit (i.e., the tank circuit not directly coupled to the input signal) should present high impedance at

its resonant frequency and the variation in the variable reactance should be large. Assuming high-Q tank circuits, the bandwidth is inversely proportional to the voltage gain and to the Q of the idling tank. The noise due to fluctuations in the variable reactance probably can be made to be of negligible consequence. However, in striving for very low noise figures, thermal noise from the idling tank will be of importance unless the idling tank is artifically cooled.

4. Maser Amplifiers: Bandwidth and Noise Considerations.

(Project 155E-78(U); A. E. Siegman)

The three-level solid-state cavity maser (or any similar resonant negative-resistance device) is essentially a regenerative amplifier. The cavity itself has an unloaded $Q = Q_o$, while the maser material has a negative $Q = -Q_m$. To have gain, the negative resistance must predominate, so that the unloaded cavity-plus-material has a negative overall $Q = -Q_m' = -Q_m Q_o/(Q_o - Q_m)$. Without loading, the cavity oscillates. High gain is obtained by loading the cavity by coupling it to an external load until the oscillations just cease.

Low noise figure is the maser's chief attraction. All presently-known materials for solid-state masers require cooling to liquid-helium temperatures to be usable. This assists in obtaining low noise figure. However, noise figure F defined with respect to a room-temperature source is now very nearly unity, and is no longer a very good parameter. One can talk about the quantity (F-1), expressed in db (which can be a negative number of db); or one can give the effective noise temperature of the amplifier; or one can suppose that the amplifier and the signal source are both at the same low liquid-helium temperature, and redefine F with respect to this low source temperature. The last procedure will be used here.

For best results, a maser should have only one input line, with a circulator to separate incident and reflected (amplified) signals. If the external Q of the input line is Q_e, the maser power gain is $G = (Q_e + Q_m')^2/(Q_e - Q_m')^2$. The condition for high gain is $Q_e \approx Q_m'$. The gain-bandwidth product is $\sqrt{G}\,B = f_o/Q_e \approx f_o/Q_m'$ for high gain. If T is the reference temperature of the source and cavity, and $-T_m$ is the negative spin temperature of the maser material, then for high gain the noise figure is

$$F = (1 + Q_m'/Q_o)(1 + T_m/T)$$

Low noise figure requires low spin temperature, and low magnetic Q_m (which is the same as low Q_m').

An alternative form is the two-port maser, which has separate input and output lines. If the input or generator line has external $Q = Q_{eg}$, and the output or load line has external $Q = Q_{eL}$, then the condition for high gain is $(1/Q_{eg} + 1/Q_{eL}) \approx 1/Q_m'$. The noise figure for high gain is given by $F = (1 + Q_{eg}/Q_o + Q_{eg}/Q_{eL})(1 + T_m/T)$, while the gain-bandwidth product is $\sqrt{G}\,B = 2f_o/\sqrt{Q_{eg}Q_{eL}}$. The optimum noise figure of the two-port maser can be made the same as the circulator maser by having heavy input coupling, $Q_{eg} \approx Q_m'$, and light output coupling,

$Q_{eL} \gg Q_m'$. However, the gain-bandwidth product is then very much worse. In addition, the output load must be cooled, or a cooled isolater must be used in the output line, to reduce noise coming back into the cavity from the load. This is not true of the circulator maser. The two-port maser can have the same gain-bandwidth product as the circulator maser by making the two couplings equal, $Q_{eg} = Q_{eL} \approx 2Q_m'$, but the noise figure is then worsened by 3 db, and the load-cooling problem is even more important.

Possible gain-bandwidth products with presently known maser materials are small (e.g., a few hundred kc at 30-db gain). Some increase may be possible by using several coupled cavities in series, or a narrow-band traveling-wave type of circuit, but the natural Q (line width) of the material itself will then become important. However, very good noise figures are expected (3 to 6 db with respect to helium temperatures, or amplifier noise temperatures of 10 to 20°K).

A solid-state maser amplifier is nearing completion. Ten microwatts of power output as an oscillator at 3000 Mc are expected, with a pumping-power input of a few milliwatts at 9600 Mc. Power output as an amplifier in the linear region will, naturally, be somewhat less. The first crystal to be used will be potassium chromicyanide, $K_3Cr(CN)_6$, in about ½% concentration in a magnetically-neutral base crystal of $K_3Co(CN)_6$.

SESSION V A (11:00-12:10) (Rehearsal Hall)

NETWORK AND SYSTEM THEORY (UNCLASSIFIED)

CHAIRMAN: W. W. HARMAN

1. *Network Synthesis*

(Tasks 24F, 24H; W. W. Harman and D. F. Tuttle, Jr.)

a. Computer Techniques

Synthesis procedures which use an iterative procedure exploiting The IBM 650 computer have been previously reported for distributed amplifiers and amplifier chains. With these iterative techniques, one starts from an assumed form for the network, and the method facilitates convergence on optimum element values. This method has recently been applied to the split-band amplifier (for wide-band amplification) in which the frequency range to be amplified is split into two portions, which are then amplified in separate channels.

Another network application of computers consists of using a computer to obtain an approximate solution to the differential equation describing a nonlinear network, the approximate solution consisting of a sum of exponential terms. The coefficients are determined by the initial value and derivatives. In effect, the nonlinear system is replaced by an approximating linear system whose element values depend upon the initial conditions.

b. Single-Inductor Synthesis.

This investigation is concerned with the problem of constructing an R-C network with a single inductor (and, perhaps, an ideal transformer) to have a specified impedance function. The necessary and sufficient conditions that the function be realizable are found to be that (1) it be positive real, (2) it have no more than one pair of complex zeros, (3) the real poles and zeros be simple, and alternate.

c. Matched-Filter Studies

A comparative study of three types of matched-filter pairs has been carried out. These types are the tapped-delay-line, multiple-bandpass, and split-allpass filters. In general, the tapped-delay-line filter appears to be superior; however, the multiple-bandpass argument proves to be one quite good way to arrive at an impulse response which may then be actually realized by a tapped-delay-line filter.

d. Delay-Line Sections in Networks.

This study has been concerned with the analysis and synthesis of networks in which ideal delay-line sections are admitted as elements in addition to the usual R, L, and C. Synthesis for prescribed impulse responses which have discontinuities in amplitude or slope, or which are identically zero after a particular time, is facilitated by the addition of this fourth element kind.

e. Statistical Decision Theory Applications.

Previously reported work has dealt with the use of decision-theoretical approaches to find the best network or system to perform a certain statistical task--estimate range to a radar target, detect the presence of a signal in noise, estimate a modulation envelope, etc. In most of these problems some *a priori* probability distributions were assumed, and some sort of 'cost' function; the best system is then the one which minimizes the average cost.

Recently some study has been made of a very interesting approach known as 'comparison of experiments.' By this theory one can compare two proposed 'experiments' (an example of an 'experiment' might be the determination of the presence or absence of a signal, or of the delay of a radar pulse) and, if the two are 'comparable,' state that one is 'more informative' than the other for any *a priori* data and cost function.

Other work includes some statistical studies of an idealized radar problem.

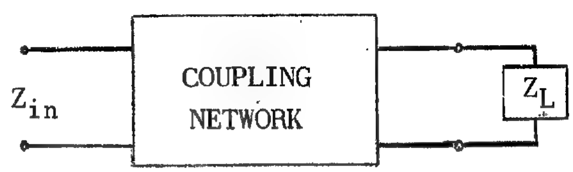
2. *Sampled-Data Control Systems (Task 24S; G. F. Franklin)*

Projected research in this field includes a study of the characteristics and limitations of practical sampled-data control systems, and an experimental and theoretical study of linear and nonlinear filters for the restoration of data from samples.

3. *Transistor Circuits (Tasks 24J and 24F, NSF G-2426; J. G. Linvill and D. F. Tuttle, Jr.)*

a. Coupling Networks (24F)

Synthesis procedures are being sought to design coupling networks for a class of problems of great practical interest which fall outside of the range of current synthesis techniques. In several practical applications, notably in the design of interstages or coupling networks at the input or output port of a transistor amplifier, the designer is required to find a lossless coupling network which will present approximately a prescribed sequence of input impedances at a set of frequencies when it is terminated in a prescribed sequence of impedances at these frequencies (Fig. A).



freq	Z_L	Z_{in}(desired)
f_1	Z_{L1}	Z_{in1}
f_2	Z_{L2}	Z_{in2}
...	...	...
f_n	Z_{Ln}	Z_{inn}

Fig. A.-Specifications for the design of a coupling network.

The problem is different from those for which the usual techniques apply in that the prescribed load impedance is not necessarily a simple resistance nor the impedance of a simple network. Also the desired input impedances are not given as functions of frequency but given instead as a sequence of values in tabular form. The aim is to extend

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synthesis techniques to these problems and thereby to bring to practical design problems some of the powerful methods (or modifications of them) which have been developed in modern network theory. Some interesting and useful techniques have been developed to this point in the research and work is continuing to develop additional methods.

b. Lumped Models of Semiconductor Devices (24J, G-2426)

Study of large-signal applications and of the avalanche phenomenon in transistors has led to a new lumped model which conveniently relates terminal properties of the transistor to its internal physics. The conventional representations of transistors for small-signal cases and the Ebers-Moll model for large-signal cases correspond to simple forms of the new model. In addition to representing behavior in the familiar cases, the lumped model represents the terminal properties associated with avalanche multiplication, punch through, minority-carrier storage, built-in fields of drift transistors and photo-generation of hole-electron pairs. The design of circuits using any of these phenomena is facilitated through use of the lumped representation.

In the conventional approach to obtaining a model of the transistor, the differential equations expressing equilibrium of the physical processes in the transistor are solved and the transcendental solutions are approximated for convenience by rational functions. In the present treatment, the physical relationships applying on the basis of vanishingly small elements are applied to finite elements and the corresponding terminal relationships are rational functions. Thus, in the new approach, the order of the procedures of solution and approximation are reversed. The new order of procedure gives further insight to transistor operation, leads to the old results in the simple cases and to new or simpler solutions in the more complicated situations.

c. Semiconductor Voltage Comparators (24J)

An ideal voltage comparator indicates whether a voltage being observed is above or below a prescribed reference level. The quality of a comparator is determined by the narrowness of the range of uncertainty, the freedom from dependence upon environmental conditions, the speed of response, and the smallness of loading of the circuit being observed. The purpose of the present study is to determine the fundamental limitations to semiconductor voltage comparators and to select designs for best performance.

Voltage comparators ordinarily involve a nonlinear element with properties sharply dependent upon the impressed voltage. Semi-conductor diodes have an apparent advantage over tube diodes for this function since their characteristics inherently posses sharper nonlinearity. In one particular comparator being considered, the nonlinear element is a part of a feedback structure which becomes unstable when the input voltage reaches the reference level.

A principal limitation to the performance of comparators is the

dependence of their characteristics upon the temperature. A diode-bridge arrangement serving as the nonlinear element can theoretically show no dependence upon temperature in spite of drifts in individual diodes. Using a diode bridge and a single-stage transistor amplifier, a comparator has been made which has a region of uncertainty 30-mv wide for a temperature range from 25° to 55°C. It is anticipated that additional work will improve the performance.

SESSION V B (11:00-12:10) (Auditorium)

HIGH-POWER TRAVELING-WAVE TUBES AND KLYSTRONS (UNCLASSIFIED)

CHAIRMAN: M. CHODOROW

1. *Megawatt Cloverleaf Traveling-Wave Tube*
(AF-1924; J. V. Lebacqz)

During the past year a severed structure of the cloverleaf type was built and tested here at Stanford. The structure included twelve sections on either side of the sever. The results, although not completely up to expectations, were quite satisfactory. A peak power in excess of one megawatt was observed over a part of the band. The small-signal gain approached 30 db, with saturation gain of about 23 db. The efficiency was poorer than expected, mostly because the beam transmission was low, approximately 65 to 75 per cent. Gain was observed at small signals over a frequency range from 2750 to 3200 megacycles. The large-signal gain as measured from 2900 to 3130 megacycles had less than 3 db variation. It is believed that the large-signal gain would have stayed substantially flat down to about 2800 megacycles, but the lack of a suitable driver prevented us from making measurements in this frequency region.

Since these tests were run, work has been continued on the cloverleaf traveling-wave tube in two main directions. First, to improve the beam transmission, a beam tester was built and tested which has shown that the cathode, with slight modifications in the magnetic focusing system, can readily give nearly 100 per cent transmission. This change in the magnetic focusing system will be incorporated in the tube now being built. The second phase of the work has been concerned with increasing the attenuation in the tube in a higher pass band, a pass band which is due to coupling-slot resonances. There has been some tendency to oscillate at these high frequencies (higher than 4000 Mc) at high-voltage operation, and we have been trying to produce a large differential in attenuation between that in the operating pass band and that in the slot pass band, with some considerable success.

2. *Windows*
(ONR-26; J. Jasberg)

The first high-power klystron (now capable of 30 megawatts output) was constructed at Stanford at a time when the only available output window was capable of handling about 1 megawatt of power. Since that time, a large amount of effort has gone into an attempt to provide a long-lived window for this and similar tubes developed here. At the present time, this work largely involves ceramic windows of various designs and materials. Some improvements have been made, and it is now possible to run tubes which are continuously pumped for times of the order of 1500 hours.

Attempts to make sealed-off tubes with long lives have not been particularly successful so far due to punctured output windows. A discussion of the nature of fail-

ures and of the lives of windows will be given. A number of possible theories have been suggested but as yet none of these can be positively confirmed. Life testing of windows is a problem and a high-power traveling-wave recirculator is under construction to aid this program. Some possible experimental checks on the various theories will be outlined.

3. Research in Propagating Circuits for High-Power Traveling-Wave Tubes (AF-1924, ONR-23; M. Chodorow)

Although some circuits suitable for high-power traveling-wave tubes have been designed and successfully tested, these are narrower in bandwidth than is desired for some applications, and it is not at all certain that they are optimum in other respects, even though they seem quite satisfactory. Investigations are being conducted on other circuits, some of which may in some respects be better than the ones successfully used up to now. Among these circuits is the stub-supported ring-bar structure which is better in bandwidth and in interaction impedance than presently available high-power circuits, but is more limited in average-power-handling capability. Another circuit consists of a series of cavities inductively coupled by means of multiple inverted coupling loops. Tests so far indicate that this circuit may have a considerably wider band than the cloverleaf structure and about the same impedance. Another class of circuits involves coupling between alternate cavities as a method of shaping the propagation characteristic in desirable fashion. The results of cold tests on these various circuits and possible applications of the circuits will be described.

25X1

SESSION VI B (1:30-2:45) (Auditorium)

MICROWAVE ELECTRONICS (UNCLASSIFIED)

CHAIRMAN: H. J. SHAW

1. *Periodic Deflection Focusing (SC-3(78); G. Kino)*

A new method of focusing an electron beam for use in traveling-wave tubes and related devices has been proposed by P. A. Sturrock. The system, called *'Periodic Deflection Focusing,'* depends on the focusing effect on an electron beam which occurs when the beam is periodically deflected in one direction and then another. Theoretical analysis has been carried out for both electrostatic periodic deflection focusing and magnetic periodic deflection focusing. The best-known example of periodic electrostatic deflection focusing is slalom focusing. Periodic magnetic deflection focusing, however, would appear to have great advantages over the more common periodic magnetic-focusing schemes, because, with the configuration used, much higher fields are obtainable for a given size of magnet. As the focusing forces are proportional to the square of the magnetic field, it should therefore be possible to focus very high values of beam current. In addition, it should be possible to use a variation of the method to contract the diameter of an electron beam adiabatically, so that the gun-design problems should not limit the current density obtainable.

It is planned to test magnetic periodic deflection focusing in the near future. A beam tester is being built for use with a hollow electron beam on which it will be possible to check the theoretical predictions.

2. *Electron Guns With Curved Electron Trajectories (AF-1930; P. Kirstein)*

A new class of electron guns in which the electron trajectories are curved rather than rectilinear will be described. By making use of the Hamilton-Jacobi equation, Poisson's equation and the equation of continuity of charge, it has been possible to obtain electron-trajectory solutions which take into account the effect of space charge. At the moment, the design of shielded guns to produce solid or hollow beams is being investigated in which the cathode is either a section of a cone or a section of a circular cylinder. It is also proposed to investigate the design of a type of gun intended to produce sheet beams in which the cathode is a portion of an equiangular spiral sheet. It is possible that the method may also be useful in the design of crossed-field electron guns with magnetic field parallel to the cathode, but investigation of this possibility is not planned for the near future. It is proposed to design the electrode shapes to produce the beams by a procedure analagous to that used in the Pierce gun. However, a method of gun design proposed by J. E. Piquandar and used with success in France will also be investigated.

3. Field Emission
(ONR-23; J. Fontana)

Field-emission cathodes with dimensions of about one micron can provide currents of the order of one ampere under pulsed operation. This current is controlled by the anode voltage according to a very nonlinear law which remains true at extremely high frequencies. Possible applications of these unusual properties to microwave tubes are being investigated.

Calculations will be shown giving the harmonic content of a field-emission beam produced by the r-f excitation of a point emitter which is biased by a d-c voltage. It will be shown that the curve of harmonic amplitudes can be expressed as a function of dimensionless ratios relating these voltages to certain parameters which depend upon the emitter itself and the operating conditions chosen. The results indicate that the curve has a shape similar to an error curve, and that, under operating conditions compatible with a reasonable emitter life, the power contained in the eighth or tenth harmonic is still quite appreciable.

4. Generation of Sub-Millimeter Waves
(SC-85; K. Mallory)

The production of electro-magnetic radiation at wave lengths less than a millimeter using conventional tube techniques is very difficult because of the minute size of the element dimensions for such wave lengths. An alternative approach involves producing very small tight bunches of electrons at high energies (2 to 3 Mev). Such high-energy electrons can be made to generate very short-wave-length radiation by several means; either by producing transverse oscillation of the electrons or by passing such a beam through a cavity or a propagating circuit of suitable design. For wave lengths large compared to the bunch size, the electrons of each bunch will radiate coherently and produce considerable amounts of power. An experiment designed to produce sub-millimeter wave radiation by this means will be described. It involves a small X-band linear electron accelerator which will produce electrons of several million volts of energy, the electrons being tightly bunched; it is then intended to use such electrons to produce a considerable amount of radiation at wavelengths below a millimeter, either by 'undulation' or by straight frequency-multiplier action at a harmonic of the original accelerator frequency.

GENERAL TOUR OF LABORATORY FACILITIES

TOUR STARTS AT 3:15 P M. AT STEPS IN FRONT OF DINKELSPIEL AUDITORIUM ON FRIDAY AFTERNOON.

THIS GUIDED TOUR REQUIRES ABOUT ONE AND ONE-HALF HOURS AND IS INTENDED TO BE A QUICK INSPECTION OF THE INSTALLATIONS LISTED BELOW.

APPLIED ELECTRONICS LABORATORY (CLASSIFIED)

VACUUM-TUBE SHOP
SYSTEMS DEVELOPMENT AREAS
SCREEN ROOM

ELECTRONICS RESEARCH LABORATORY

COMPUTER FACILITIES
TRANSISTOR AND CIRCUIT LABORATORIES
STUDENT VACUUM-TUBE TECHNIQUES SHOP
VACUUM-TUBE SHOP
TRANSVERSE-FIELD KLYSTRON
HELITRON
SOLID-STATE MASER
PERIODIC FOCUSING OF ELECTRON BEAMS
TWELVE-FOOT-LONG BACKWARD-WAVE OSCILLATOR
VACUUM-TUBE DISPLAYS
RADIO-PROPAGATION LABORATORIES

HIGH-ENERGY PHYSICS LABORATORY

MARK-III LINEAR ACCELERATOR
HALF-WAY STATION
END STATION AND BUNKER
MARK-II LINEAR ACCELERATOR
TUBE SHOP
KLYSTRON-PROCESSING STATION

MICROWAVE LABORATORY

VACUUM-TUBE DISPLAY
MARK-IV 70-MEV ACCELERATOR
X-BAND ACCELERATOR
ELECTRON-BEAM ANALYZER
MASERS
ELECTRON-VELOCITY SPECTROGRAPH

DEMONSTRATIONS AT ERL

1. Solid-state masers - Project 155E (A. E. Siegman) ERL 240
   This will be a non-operating display showing the double dewar flask and other special apparatus needed for solid-state maser investigations.

2. External-circuit traveling-wave tubes - Project 191A (G. A. Loew) ERL 262
   These tubes use a series of hollow cylinders for coupling to the electron beam. The delay lines are external to the vacuum envelope. Two types of construction are shown, one for a forward-wave amplifier and the other for a backward-wave oscillator.

3. Low-noise amplifier - Project 305T (F. B. Fank) ERL 221
   An experimental transverse-field klystron operating in the 200-400 Mc range which is being investigated as a possible low-noise amplifier.

4. Crossed-field device - Project 385N (T. Sato) ERL 254
   A tube built to investigate experimentally the crossed-field interaction of an electron beam at microwave frequencies.

5. Backward-wave-oscillator beam analyzer - Project 403W (J. Gewartowski) ERL 259
   A twelve-foot-long backward-wave oscillator operating at 80 Mc which has a velocity analyzer built in so that instantaneous beam bunching may be observed on a fluorescent screen.

6. Helitron oscillator - Project 404W (G. Wada) ERL 259
   This tube was built to demonstrate the behavior of the Helitron. The device has the properties of the M-type BWO, (i.e., high efficiency and electronic tuning) but needs no focusing magnet.

7. Hollow-beam electrostatic focusing - Project 406W (C. C. Johnson) ERL 254
   This demountable tube is being used for the experimental investigation of electrostatic focusing of hollow beams.

8. Transistorized circuitry - Project 755K
   Video amplifier (J. Spilker) ERL 106
   An amplifier using capacitors as the only reactive elements (RC degeneration) is shown. The amplifier uses four SB100 or 2N247 transistors, has a gain of 65 db and a bandwidth of 4.3 Mc.

   Sweep generator (E. Yhap) ERL 106
   This linear-sawtooth generator (1% or less nonlinearity) has high output compared to supply voltage, fast recovery and exceptional ability to synchronize with most triggering waveforms.

   Pulse-length window (R. Windecker) ERL 106
   This circuit gives an output indication if a pulse lies between two predetermined pulse lengths. The two limits of the window may be set independently.

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SERVICE-SPONSORED ELECTRONICS PROGRAM AT STANFORD UNIVERSITY

CONTRACT NO.	AREA	SUPERVISOR	ABBREVIATED DESIGNATION
STANFORD ELECTRONICS LABORATORIES (ERL, AEL, RPL)			
AF18(603)53	MICROWAVE SPECTROHELIOGRAPH	BRACEWELL	AF53
AF18(603)126	WHISTLERS	HELLIWELL	AF126
AF19(604)1830	AURORAL RADIO PROPAGATION	PETERSON-VILLARD	AF1830
AF19(604)1847	GEN. STUDIES: RADAR RECEIVERS	RAMBO-WATKINS	47
AF19(604)2075	METEOR RADAR	VILLARD	AF2075
AF19(604)2193	METEOR RATE AND RADIANT STUDIES	ESHLEMAN	AF2193
AF33(600)27784	ECM PROGRAM	RAMBO	84
CST-6030	VERTICAL INCIDENCE MEASUREMENTS	HELLIWELL	C30
CST-6033	SFERICS	HELLIWELL	C33
DA36(039)SC-72804	EXTERNAL-CIRCUIT TWT STUDY	SPANGENBERG	04
DA36(039)SC-73151	APPLIED RES. ECM TECHNIQUES	RAMBO	51
DA36(039)SC-73178	APPLIED RESEARCH: MICROWAVE TUBES AND DEV.	WATKINS	78
N-123(61756)-4191A	EXPERIMENTAL ECM EQUIPMENT	RAMBO	91A
NONR-225(24)	CONSOLIDATED ELECTRONICS		24
NONR-225(25)	MICROWAVE TUBE RESEARCH	WATKINS	25
NONR-225(27)	MAGNETO-IONIC DUCT PROPAGATION	HELLIWELL	27
NSF-G2426	AVALANCHE PHENOMENA IN TRANSISTORS	LINVILL	NSF26
Y/1.16/179	AURORA AND AIRGLOW	PETERSON	Y/1.16
Y/1.38/41	ANTARCTIC METEOR RADAR	VILLARD	Y/1.38
Y/1.44/183	RADIO WAVE ABSORBTION AURORA AND AIRGLOW	PETERSON	Y/1.44
Y/6.10/20	WHISTLERS	HELLIWELL	Y/6.10
Y/6.12/62	FIXED FREQUENCY BACKSCATTER	PETERSON	Y/6.12
HANSEN LABORATORIES (MICROWAVE LABORATORY) SUPERVISORS: E L GINZTON AND M CHODOROW			
AF19(604)1924	HIGH-POWER TUBES	CHODOROW	AF1924
AF19(604)1930	BEAM TUBES	CHODOROW	AF1930
AT(04-3)-21P.A.#1	ACCEL. TECH	NEAL-CHODOROW	PA-1
DA36(039)SC-71178	MOLECULAR OSC	JAYNES	SC-71178
DA36(039)SC-72785	SUB-MILLIMETER WAVES	MALLORY-CHODOROW	SC-85
DA36(039)SC-72178	(WITH ERL)	CHODOROW	SC-3(78)
NONR-225(26)	VELOCITY-MODULATED TUBES	CHODOROW	ONR-26
N6ONR-25123	KLYSTRON AND TW TUBES	CHODOROW	ONR-23

ELECTRONICS PROJECTS AT STANFORD UNIVERSITY

FOLLOWING ARE ACTIVE PROJECTS, LISTED WITH THE PERTINENT CONTRACT NUMBER, DESIGNATION, AND CLASSIFICATION, AND THE PERSON AVAILABLE AT THIS TIME FOR DETAILED DISCUSSIONS.

FOLLOWING THE NAME IS THE PLACE AND ROOM DESIGNATION.

I. ELECTRON DEVICES (ERL) (TRAVELING-WAVE TUBES, BACKWARD-WAVE TUBES, SPECIAL PURPOSE TUBES, SPECIAL TUBE TECHNIQUES, SOLID-STATE MICROWAVE AMPLIFIERS)

	1.1 GROUP A	GROUP LEADER: K. R. SPANGENBERG	ERL	266
191A-24(U)	EXTERNAL-CIRCUIT TRAVELING-WAVE TUBES	J. SPALTER		262
	1.2 GROUP B	GROUP LEADER: D. A. DUNN	ERL	205
189B-78(U)	BACKWARD-WAVE AMPLIFIER (FREQUENCY DIVIDER)	R. W. GROW		218
311B-78(U)	GENERAL TWA AND BWO STUDIES	D. A. DUNN		205
380B-HP(U)	20-40 KMC BWO	R. W. GROW		218
382B-78(U)	BIFILAR-HELIX BWO	R. W. GROW		218
459B-51(U)	HARRIS-FLOW BWO	W. R. LUEBKE	AEL	
490B-84(U)	POWER LIMITATIONS IN HELIX TUBES	R. P. LAGERSTROM	ERL	218
	1.3 GROUP E	GROUP LEADER: A. E. SIEGMAN	ERL	240A
155E-78(U)	SOLID-STATE MICROWAVE DEVICES	A. E. SIEGMAN		240A
	1.4 GROUP N	GROUP LEADER: H. HEFFNER	ERL	263
202N-24(U)	FERRITE ATTENUATORS FOR TWT'S	L. BACON		254
204N-24(U)	HIGH-POWER MICROWAVE AMPLIFIERS	H. HEFFNER		263
207N-24(U)	MAGNETRON AMPLIFIER	B. A. WIGHTMAN		254
210N-24(U)	VARIABLE-PARAMETER AMPLIFIERS	K. L. KOTZEBUE		254
307N-78(U)	GENERAL TWA AND BWO STUDIES	H. HEFFNER		263
385N-84(U)	EXPERIMENTAL INVESTIGATION OF CROSSED-FIELD INTERACTION	T. SATO		254
	1.5 GROUP T	GROUP LEADER: G. WADE	ERL	266
232T-84(U)	PULSED TWT FOR X-BAND	M. D. HARE		244A
303T-84(U)	GENERAL MICROWAVE-DEVICE STUDIES	G. WADE		266
305T-78(U)	NEW TECHNIQUES FOR LOW-NOISE MICROWAVE AMPLIFICATION	F. B. FANK		221
308T-84(U)	LOW-NOISE INVESTIGATIONS FOR X-BAND TWT	L. D. BUCHMILLER		221
313T-78(U)	HOLLOW-BEAM FOCUSING WITH COMBINED ELECTROSTATIC AND PERIODIC MAGNETOSTATIC FIELDS	C. B. CRUMLY		221D
386T-84(U)	MULTIFUNCTION BEAM-TYPE MICROWAVE TUBES	R. W. DEGRASSE	AEL	
457T-78(U)	APPLICATIONS OF HARROW-FLOW FOCUSING TO TWT'S AND BWT'S	C. B. CRUMLY	ERL	221D

1.6	GROUP W	GROUP LEADER: D. A. WATKINS	ERL 263
383W-84(U)	CROSSED-FIELD-TUBE GUN	D. A. WATKINS	263
401W-24(U)	NOISE STUDIES	A. SHAW	259
403W-24(U)	BWO STUDIES	J. W. GEWARTOWSKI	259
404W-24(U)	HELITRON OSCILLATOR	G. WADA, J. L. JONES	259
405W-24(U)	STRUCTURES FOR HIGH-POWER TWT'S	D. G. DOW	259
406W-84(U)	HOLLOW-BEAM ELECTROSTATIC FOCUSING	C. C. JOHNSON	254
453W-78(U)	CONSTRUCTION TECHNIQUES FOR HIGH-POWER TWT'S	W. H. KOHL	242
458W-78(U)	HIGH-POWER HOLLOW-BEAM TWA'S	M. I. DISMAN	254

1.7	GROUP ML	GROUP LEADER: M. CHODOROW (SEE ALSO UNDER SEC.VII)	
250ML-78(U)	HIGH-POWER WINDOWS	J. JASBERG	ML 8
352ML-78(U)	FLOATING-DRIFT-TUBE KLYSTRONS	M. CHODOROW	ML 3
353ML-78(U)	HIGH-POWER KLYSTRON OSCILLATOR	M. CHODOROW	ML 3

II SYSTEMS TECHNIQUES (AEL)

2.1	GROUP C	GROUP LEADER: J. M. PETTIT	ERL 104
290C-84(U)	WIDEBAND I-F AMPLIFIER	M. M. MCWHORTER	105
292C-84(U)	WIDEBAND TRANSISTOR AMPLIFIER	R. M. SCARLETT	109
302C-84(U)	STUDIES OF TWT'S AS I-F AMPLIFIERS	M. M. MCWHORTER	105

2.2	GROUP J	GROUP LEADER: R. C. CUMMING	AEL
701J-84(C)	SURVEY OF ELECTRONIC WARFARE PROBLEMS		
702J-84(C)	AIRBORNE CM AGAINST JAMMER-LOCATING SYSTEMS		
703J-84(C)	MOLECULAR AMPLIFIER APPLICATION STUDY		
704J-47(C)	THEORY OF RADAR RECEPTION IN THE PRESENCE OF JAMMING		

2.3	GROUP K	SPECIAL PROJECTS	
754K-84(C)	MISCELLANEOUS ASPECTS OF RADAR CM AND CCM	R. R. BUSS	AEL
755K-51(U)	TRANSISTOR CIRCUIT FEASIBILITY STUDIES	M. M. MCWHORTER	ERL 105

2.4	GROUP L	GROUP LEADER: R. E. MILLER	AEL
460L-51(C)	APPLICATION OF EXTENDED-RANGE PROPAGATION TO PASSIVE DETECTION		
461L-51(U)	EFFECTS OF TROPOSPHERIC IRREGULARITIES ON MICROWAVE PROPAGATION	A. T. WATERMAN	
801L-51(C)	INTERCEPT TECHNIQUES FOR APPLICATION AGAINST AIRBORNE RADARS		
803L-84(C)	FIELD TESTS OF S-442 POWER AMPLIFIER		

2.5	GROUP Q	GROUP LEADER: D. J. GRACE	AEL
152Q-51(C)	X-K BAND SUPERHETERODYNE RECEIVER	J. C. DE BROEKERT	
444Q-84(C)	MAGNETIC AMPLIFIER STUDY	J. C. DE BROEKERT	
507Q-84(C)	ELECTRONIC SIGNAL-SORTING TECHNIQUES	D. J. GRACE	
508Q-51(U)	BROADBAND MICROWAVE CRYSTAL HARMONIC GENERATOR TECHNIQUES	D. J. GRACE	
509Q-51(U)	EXPERIMENTAL EVALUATION OF NEW MICROWAVE CRYSTALS AND CRYSTAL MOUNTS	M. CRANE	
510Q-51(U)	TUNABLE MICROWAVE FILTERS USING FERRITES	M. CRANE	
511Q-51(C)	EXPERIMENTAL EVALUATION OF IMPROVED TWT'S IN THE S-152 RECEIVER	G. STANLEY	

2.6	GROUP R	GROUP LEADER: W. R. KINCHELOE	AEL
502R-84(U)	EXTERNAL FOCUSING TECHNIQUES	R. FALCONER	
503R-84(C)	OPERATING CHARACTERISTICS OF MICROWAVE TUBES	W. R. KINCHELOE	
554R-84(C)	SUPERREGENERATIVE OPERATION OF BWO'S	C. J. SHOENS	
555R-51(C)	A BROADBAND UTILITY RECEIVER USING IAGC	W. R. KINCHELOE	
556R-47(C)	NONSATURATING BROADBAND LIMITER TECHNIQUES	J. J. YOUNGER	
601R-51(C)	S-BAND SEARCH-LOCK RECEIVER	W. R. KINCHELOE	

2.7	GROUP S	GROUP LEADER: J. L. GRIGSBY	AEL
441S-84(C)	DECEPTION REPEATER FOR C-W DOPPLER SYSTEMS	M. WRIGHT	
443S-84(C)	SPECTRUM-ANALYSIS TECHNIQUES	M. WRIGHT	
553S-51(U)	NEW TECHNIQUES FOR WIDEBAND CM RECEIVERS	J. L. GRIGSBY	
602S-91A(C)	USNAMTC EXPERIMENTAL CM EQUIPMENT	M. WRIGHT	
604S-47(C)	ECM SIMULATOR	R. G. SWEET	
605S-51(C)	FIELD EVALUATION OF S-480 SYSTEM	J. L. GRIGSBY	
609S-84(C)	S-BAND TWT MONITOR RECEIVER	M. WRIGHT	
610S-84(C)	ANGULAR DECEPTION REPEATER-JAMMER	M. WRIGHT	

BASIC AND GENERAL RESEARCH (JOINT SUPPORT CONTRACT NONR 225(24); SPECIFIC CONTRACTS AS LISTED) (SEE ALSO UNDER MICROWAVE LABORATORY LISTING, SEC. VII)

III MICROWAVE TUBES

3.1 TASK 24-A AND DA36(039)SC-72804 SUPERVISOR: K. R. SPANGENBERG ERL 266
(SEE ALSO UNDER 1.1)

A. EXTERNAL-CIRCUIT TRAVELING-WAVE TUBES

1. GENERAL STUDIES — G. A. LOEW — ERL 262
2. PERIODICALLY LOADED HELIX CIRCUITS — G. A. LOEW

3.2 TASK 25-E SUPERVISOR: A. E. SIEGMAN (SEE UNDER 1.3)

3.3 TASK 24-N SUPERVISOR: H. HEFFNER (SEE UNDER 1.4)

3.4 TASK 24-W SUPERVISOR: D. A. WATKINS (SEE UNDER 1.6)

IV TRANSISTOR RESEARCH (SEE ALSO UNDER 2.1)

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2.	CENTIPEDE MULTI-MEGAWATT TRAVELING-WAVE-TUBE AMPLIFIER	A. F. PEARCE	6

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AF19(604)1830	AURORAL RADIO PROPAGATION	A. H. PETERSON	303
AF19(604)2075	OPERATION SMOKE-PUFF (STUDIES OF MAN-MADE ION CLOUDS)	O. G. VILLARD, JR.	305
AF19(604)2193	METEOR-RATE AND RADIANT STUDIES	V. R. ESHLEMAN	303
CST-6030	VERTICAL-INCIDENCE MEASUREMENTS	R. A. HELLIWELL	301
CST-6033	SFERICS	R. A. HELLIWELL	301
NONR-225(27)	MAGNETO-IONIC DUCT PROPAGATION	R. A. HELLIWELL	301
Y/1.16/179	AURORA AND AIRGLOW	A. H. PETERSON	303
Y/1.38/41	ANTARCTIC METEOR RADAR	O. G. VILLARD, JR.	305
Y/1.44/183	RADIO-WAVE ABSORBTION, AURORA, AND AIRGLOW	A. H. PETERSON	303
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SIGNAL CORPS AUTHORITY (TUBES) COMMANDING GENERAL EVANS SIGNAL LABORATORY BELMAR, NEW JERSEY ATTENTION: HAROLD J. HERSH, SCCL	ALL REPORTS ON DA36(039)SC-73178 TUBE REPORTS ON DA36(039)SC-63189
SIGNAL CORPS AUTHORITY (SYSTEMS) COMMANDING GENERAL EVANS SIGNAL LABORATORY BELMAR, NEW JERSEY ATTENTION: MR. I. O. MYERS, SIGEL-CD	ALL REPORTS ON DA36(039)SC-73151 SYSTEMS REPORTS ON DA36(039)SC-63189
AIR FORCE AUTHORITY COMMANDER WRIGHT AIR DEVELOPMENT CENTER WRIGHT-PATTERSON AIR FORCE BASE, OHIO ATTENTION: MR. FRED BARBECK, WCLGL-7	REPORTS ON AF33(600)27784
AIR FORCE CAMBRIDGE RESEARCH AUTHORITY COMMANDER AIR FORCE CAMBRIDGE RESEARCH CENTER L. G. HANSCOM FIELD BEDFORD, MASSACHUSETTS ATTENTION: AF19(604)1847--L. C. MANSUR	REPORTS ON AF19(604)1847
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5	R. D. MIDDLEBROOK R. M. SCARLETT	7-12-56	AN APPROXIMATION TO ALPHA OF A JUNCTION TRANSISTOR
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